COOPERATIVE EFFORTS IN ATMOSPHERIC EFFECTS ASSESSMENT

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ABSTRACT

This first Battlespace Atmospherics Conference reflects the increasing emphasis on joint operations, not only among the different branches of the military services but also with allies, such as NATO countries. Atmospheric effects assessment for military operations or hardware design would not be at the state it is today were it not for joint R&D programs in the past. A few of such programs are reviewed and highlights of their accomplishments presented. They include the tri-service Atmospheric Transmission Plan and joint programs performed by Research Study Group 8 of Panel 4 of the Defense Research Group (DRG) of NATO; evaporation ducting assessment addressed by Research Study Group 6 of Panel 3 of DRG/NATO; measurement of variability of coastal atmospheric refractivity and EO parameters conducted under sponsorship by the Office of Naval Research involving many participants. It is concluded that cooperative programs not only leverage increasingly scarce resources they also provide much broader perspectives resulting in more generally applicable solutions.

INTRODUCTION

Research and development (R&D) efforts, especially those that require data from different geographic regions, are most efficiently carried out cooperatively. This is especially true for military R&D in the post-cold war environment where defense budgets are significantly reduced. Since this is a conference sponsored by the joint services in the U.S. and has broad international participation, it seems appropriate to review some examples of highly successful cooperative efforts. Three examples are presented: the Department of Defense Plan for Atmospheric Transmission Research and Development; evaporation ducting assessment by the DRG of NATO; and a series of coastal propagation programs for electromagnetic and electrooptical propagation assessment.

ATMOSPHERIC TRANSMISSION PLAN

In the late 1970s, the Director, Defense Research and Engineering (DDR&E) issued guidance for cooperation between the U.S. Army, Navy and Air Force in the area of transmission of optical, infrared, and millimeter wave propagation through the atmosphere (Perry, 1978). This guidance identified technical issues and assigned responsibilities to the services for their solution. The Air Force was assigned responsibility for development and maintenance of atmospheric transmission codes (such as LOWTRAN, HITRAN, MODTRAN). The Army was assigned responsibility for measurement and modeling of atmospheric propagation for battlefield conditions. The Navy was assigned responsibility for predicting propagation conditions in marine environments. For the Navy, the most pressing issue was the development of suitable marine aerosol models. The development of the first in a series of marine aerosol models is an example of using cooperatively obtained data from complex field experiments. Until that time, marine aerosol models considered by the U.S. Navy were based on a two component distribution (Wells et al., 1977). Gathman (1983) examined a large body of previously obtained aerosol data. Among them were measurements by various groups in the Atlantic, the Pacific, and the Baltic. The platforms used were U.S. and Dutch research vessels, British, German, and U.S. research towers, shore stations, and aircraft. A careful statistical analysis of the data revealed three peaks within in the aerosol size distributions suggesting a three-component aerosol model for the marine environment.

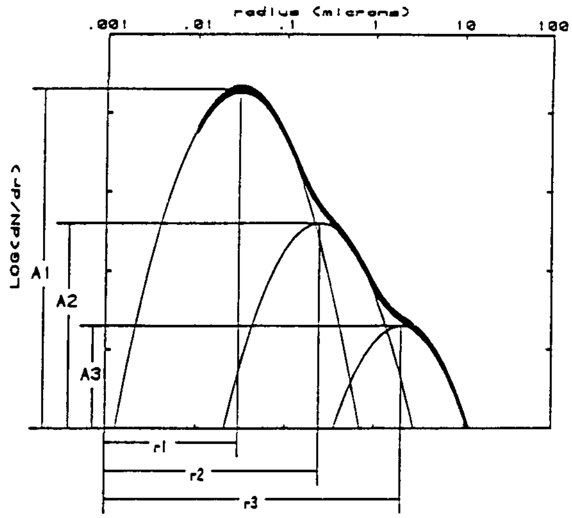

Figure 1. The Navy Marine Aerosol Model (NAM).

Consequently, a Navy Aerosol Model (NAM) was defined by a linear combination of three log-normal distributions. Figure 1 shows the three component NAM with each component characterized by a mode radius r and an amplitude A. The distribution with the smallest mode radius is the background aerosol related to the air mass characteristics and independent of the local wind parameters. The second component represents marine aerosols that can statistically be related to the 2-l-hour wind average. The third component with the largest mode radius is related to the current wind. NAM was incorporated into LOWTRAN 6 (Kneizys et al., 1983) and subsequently extended to include vertical dependencies in a model called the Navy Oceanic Vertical Aerosol Model

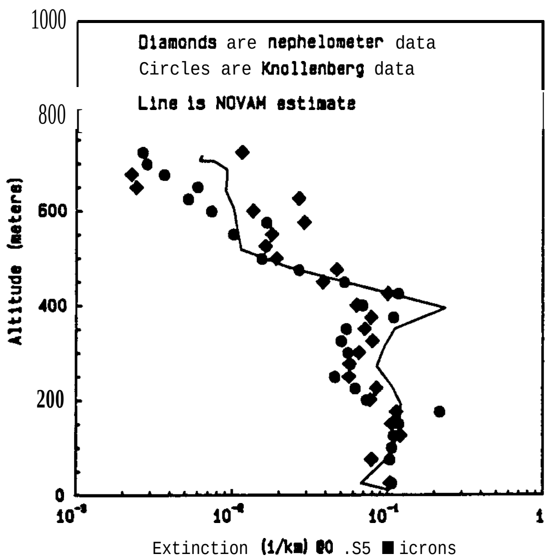

Figure 2. Extinction profiles from aerosol model NOVAM, nephelometer, and drop size distribution (Knollenberg spectrometer) measurements.

(NOVAM) (Gathman et al., 1990). Figure 2 is an example of an extinction profile at 0.55 μm wavelength calculated using NOVAM (solid line). NOVAM-derived extinction profiles compare favorably with those calculated from nephelometer (diamonds) and drop-size distribution measurements (circles). The threat to ships by sea skimming missiles and the need to detect such threats with electrooptical devices, prompted a careful investigation of near-surface drop size distributions. It was found necessary to add a fourth aerosol component to account for very large, near-surface aerosols generated by high winds under white-capping conditions. Measurement of such aerosol distributions is very difficult and was one of the objectives of a multi-national experiment conducted by Research Study Group 8 of Panel 4 (Optics and Infrared) of NATO's DRG. The experiment was called Marine Aerosol Properties and Thermal Imager Performance (MAPTIP) and conducted on the Netherland's Meetpost Noordwijk, an oceanographic platform 9 km off the Dutch coast (Jensen et al.,1993). Gathman (1996) added a fourth component to the aerosol model that is now called the Advanced Navy Aerosol Model (ANAM). This fourth component has a mode radius that is independent of wind speed and the amplitude of the distribution looses its vertical height dependence for high wind speeds. The carefully planned multi-national experiment for obtaining the data necessary to describe this fourth component is an excellent example of the need for and the success of cooperative programs.

MICROWAVE DUCTING

Atmospheric refractive layers may channel or duct electromagnetic (EM) energy very effectively. One Persistent ducting mechanism found over oceans is the so called evaporation duct. It is caused by the rapid decrease of humidity directly at the water surface to an ambient value above as shown in the left panel of Figure 3. The center panel shows radio refractivity N and the right panel modified refractivity M. The inflection point in the M-profile defines "duct height", the commonly used parameter to describe the strength of the evaporation duct. Figure 4 illustrates effects of evaporation ducting on signal strength (expressed as . . propagation loss) for different duct heights. Propagation loss increase (signal decrease) within the radio horizon with increasing duct height (between 7-20 km in figure 4) can be detrimental when trying to detect an incoming missile while propagation loss decrease (signal enhancement) at longer ranges aids detecting such missiles. Depending on frequency,

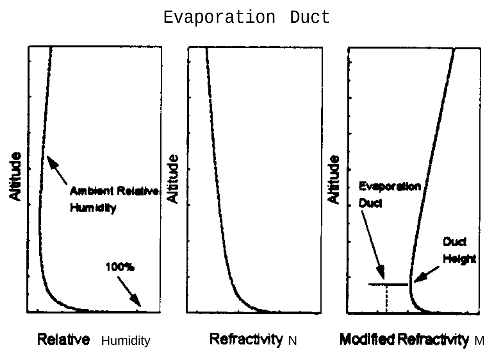

Figure3. Humidity and refractivity profiles for evaporation ducting.

evaporation ducting can produce many orders of magnitude in signal enhancement for over-the-horizon propagation. Figure 5 is an example of radar measurements under evaporation ducting conditions (Anderson, 1993). A shore-based radar at a height of 23.5 m above mean sea level and a frequency of 9.-i GHz tracked a target at height of 4.9 m between 4 - 18 km. Propagation loss is shown by the solid line for a standard atmosphere and by the triangles for the prevailing ducting condition (duct height 10 m). The radar data clearly show both the theoretically predicted initial decrease (between 8 -12 km) and a subsequent increase (> 16 km) of signal levels due to evaporation ducting.

Timely and reliable assessments of evaporation ducting effects are crucial for ship surveillance and pointdefense purposes. Profiles of vertical humidity

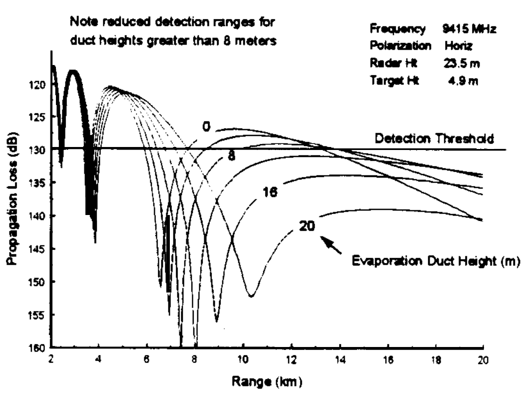

Figure 4. Propagation loss for different evaporation duct heights.

(and thereby refractivity) are not readily measurable because the most rapid profile changes occur within the first few cm above the water surface. Apart from the fact that it would be very difficult to make measurements that close to the surface, the height of the surface is only constant when averaged over several minutes. In surface layer meteorology semi-empirical relationships between fluxes of meteorological quantities and their profiles have been developed and so-called bulk measurements (i.e., point measurements at a reference height) are used to infer the meteorological profiles. The need for din-eloping, improving, and validating evaporation ducting assessment prompted several NATO cooperative efforts.

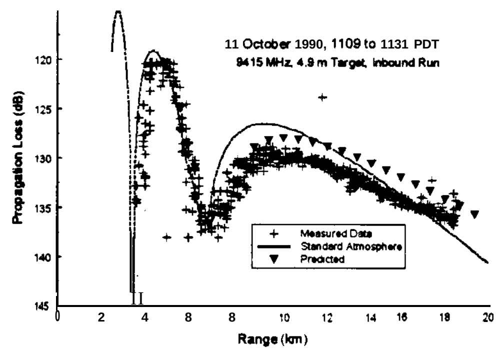

Figure 5. Measured propagation loss under evaporation ducting conditions.

One effort was a joint U.S. - Greek measurement program in the strategically important eastern Mediterranean. With support from the University of Athens, the U.S. Navy established a propagation link between the islands of Mykonos and Naxos in the Aegean Sea (Richter and Hitney, 1988). The shore station at Mykonos used vertically spaced antennas for receiving signals in the 1 - 40 GHz range radiated from the island of Naxos 35 km away. The link was operated during four measurement periods in different seasons, each lasting approximately two weeks. The objectives of these measurements were to gather statistical evaporation ducting data in this important geographic area, validate ducting models, and provide information on choosing optimal shipboard antenna heights for maximum detection ranges. An example of a two week measurement period is shown in figure 6 where the dots represent measured path loss values at 9.6 GHz for a receiving antenna at 4. 9 m and the transmitter antenna at 4.8 m above mean sea level. Most striking is the persistent signal enhancement of up to 60 dB over what would be expected under standard atmospheric conditions (the upper dashed line indicates free space path loss values and the lower diffraction path loss values)

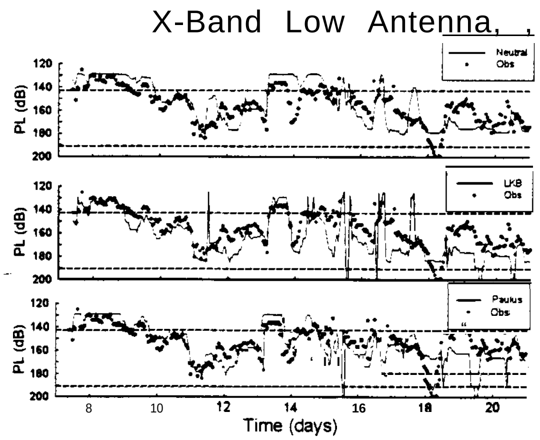

Figure 6. Path loss values under evaporation ducting conditions (dots) and evaporation duct models.

In addition to the propagation measurements in Greece, another important cooperative initiative was the establishment of NATO DRG (Panel 3) Research Study Group 6 (RSG 6). This group was chartered to *"investigate the low level maritime duct and its influence on microwave propagation ."* RSG 6 was chaired by Professor Jeske of the University of Hamburg, Germany. At the time, he and his institution had performed the most comprehensive analyses and measurements with respect to evaporation ducting (Jeske, 1965; 1971). Participating nations in RSG 6 were Canada, Denmark, Germany, Italy, Netherlands, Norway, U.K., and U.S. The group conducted meetings, measurement campaigns, and analyses and concluded its work in 1977. The final report states that *"for the evaporation duct well understood models are at hand"* (Jeske, 1977). The conclusion, that evaporation ducting effects can be reliably assessed under operational conditions, has been proven by two decades of experience even though the understanding of the physical processes governing flux-profile relationships in the surface layer have been and probably will be further improved (Liu et al., 1979; Fairrall et al., 1996). The prediction accuracy for evaporation ducting effects is not limited by an incomplete understanding of surface layer physics but by horizontal variability. Evaporation ducting is operationally significant primarily for propagation paths over tens to hundreds of kilometers. Over such distances, surface water temperature and surface layer properties will change thereby causing horizontally varying duct heights. This is the reason that newer evaporation duct models have not shown improved assessment accuracies. Rogers and Paulus (1996) have compared several models with different measurements. In figure 6, they compare three different evaporation duct models (shown by the solid lines) with the previously described measurements in the Aegean Sea. The meteorological data used as input to the different models are based on shore measurements taken at the receiving site. In the top panel, Jeske's (1971) formulation is used with the assumption of neutral stability in the surface layer. The solid line in the center panel shows calculated duct height based on the formulation of Liu et al. (1979) and the bottom panel a modification of Jeske's (1971) model by Paulus (1988). All three models do a credible job in predicting evaporation duct enhancements with none of them showing a clear superiority over the others. The conclusion reached by RSG 6 almost two decades ago still holds today and data obtained in cooperative efforts under NATO auspices remain an invaluable source of information. NATO-sponsored ducting investigations have continued, the most recent being a microwave/millimeter wave effort under NATO DRG (Panel 3) RSG 8 sponsorship (Christopher et al., 1995).

The finding that evaporation ducting effects could be reliably assessed under operational conditions was one of the foundations that made the development of the first military microwave propagation assessment system possible. The Integrated Refractive Effects Prediction System (IREPS) (Hitney and Richter, 1976) was first operationally implemented in the late 1970s aboard U.S. aircraft carriers and is now used as part of the U.S. Navy's Tactical Environmental Support System (TESS) (Sheridan et al., 1996)

The above evaporation ducting findings could not have been obtained without the cooperative effort with leading experts in the field and access to locations in other nations. Today's propagation assessment capability available to the U.S. fleet owes much to highly successful cooperative efforts performed under NATO auspices.

PROPAGATION ASSESSMENT IN COASTAL ENVIRONMENTS

The shifting military emphasis from global to regional conflicts and the experience that the latter often involve coastal areas, prompted an intensified research effort into often highly variable coastal EM and EO propagation conditions. The Navy's office of Naval Research has supported a program aimed at understanding and predicting microwave, millimeter, and electrooptical propagation in coastal environments.

Figure 7. Propagation paths during VOCAR

The first measurement program was the Variability of Coastal Atmospheric Refractivity (VOCAR) conducted in 1993 in the southern California off-shore region (Paulus, 1995). Participants included the Naval Command, Control and Ocean Surveillance Center, the Naval Air Warfare Center, the Naval Research Laboratory, the Naval Postgraduate School, the Environmental Technology Laboratory of the National Oceanic and Atmospheric Administration, and the Pennsylvania State University. One of the objectives of VOCAR was to provide long-term radio propagation data in conjunction with meteorological measurements for the development and validation of mesoscale models capable of predicting vertical refractivity structure. Another objective was to use reception of radio signals from known emitters to infer refractivity. A third objective was the development and use of satellite and ground-based remote sensors for either measuring or inferring refractivity conditions. Figure 7 shows the geometry for two propagation paths in the southern California bight Signals were radiated from the northern tip of San Clemente Island and received simultaneously in Point Mugu (path A) and in San Diego (path B). Paths A and B are nearly identical in length but traverse different areas in the southern California bight where complex mesoscale circulations (such as the Catalina eddy) and an irregular coast line with varying

Propagation Factor Time Series June 1, 1993 to September 7, 1993
SCI - Point Mugu 262.85 MHz and SCI - San Diego 262.85 MHz

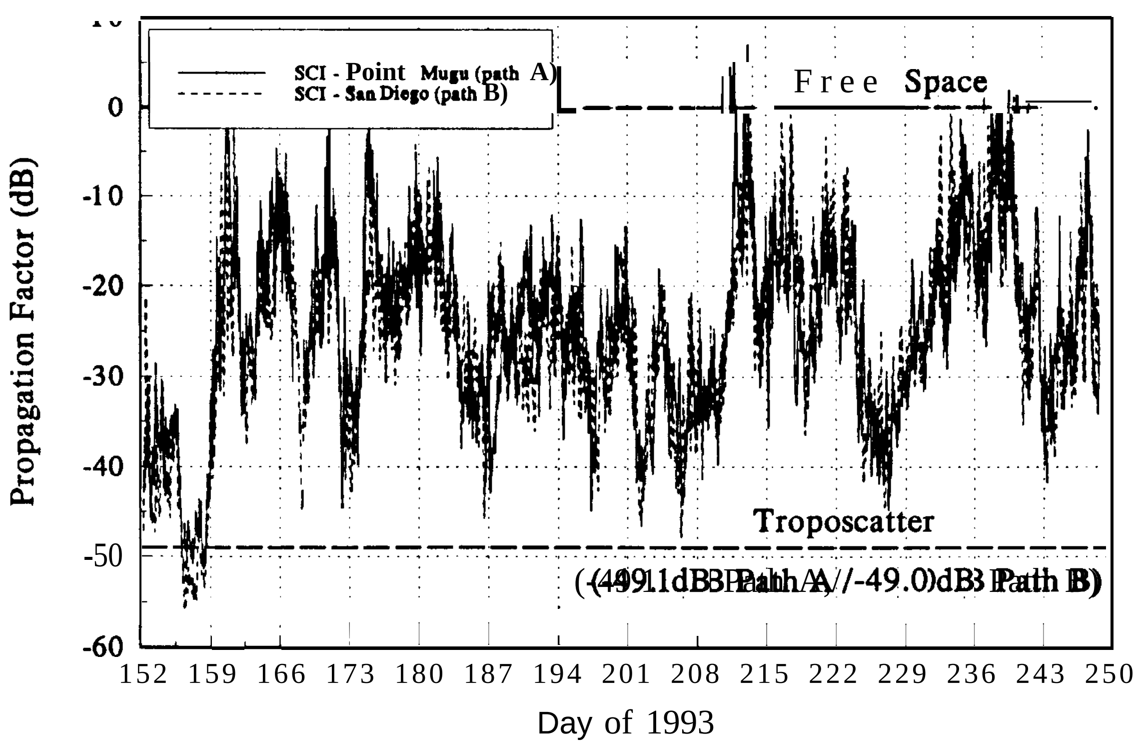

Figure 8. Long-terns propagation measurements during VOCAR.

topography might cause horizontally inhomogeneous refractivity fields. Figure 8 shows a 99-day time series of signal strength (e.xPressed here as propagation factor) for a frequency of 262.85 MHz for the two paths (Rogers, 1995). In the absence of any ducting, a propagation factor of -49 dB would be expected and in free space, it would be O dB. Over the time period

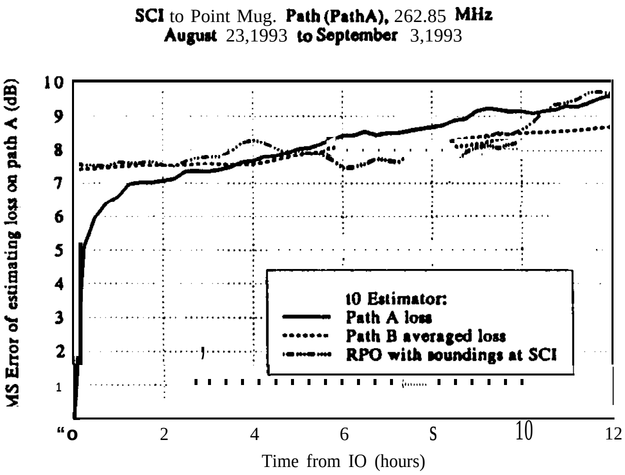

Figure 9. Propagation estimates.

displayed, the signals vary between those limits (spanning five orders of magnitude) illustrating significant ducting enhancements most of the time. The signals for the two different propagation paths follow the same trend even though there are instantaneous differences. Following the same trend indicates sufficient horizontal extent of gross refractivity structures giving confidence to the expectation that high-resolution mesoscale models eventually will be able to describe the refractive environment for propagation assessment purposes (Hodur, 1996). A subset of the data show-n in figure 8 was used for statistical analyses and to provide quantitative answers to where and how often the environment should be sampled. In figure 9, the root mean square (rms) error is plotted as a fiction of lag time (Rogers, 1995). The solid curve is the rms error based on the actual measurement over this path. At time zero, there is, of course, no error. One would expect the same zero error result at time zero if the refractivity field along path A were known precisely and a perfect propagation model applied. If the path loss value measured (or calculated based on perfect information) at time zero is used to estimate future path loss values, the error increases to approximately 6 dB within 30 minutes and to 10 dB in the next 12 hours. This information may be used to specify the frequency for updating environmental measurements. The other two curves in figure 9 show the rms error if either the path loss measured over the other path (B) is used to estimate path loss values for path A or if radiosonde-inferred refractivity profiles at San Clemente Island (SCI) in conjunction with the Radio Physical Optics (RPO) model (Hitney, 1992) are used to calculate path loss for path A. All three curves converge to the same range of rms errors which is a good indication of the prediction accuracy that is feasible for the conditions and geometries involved.

Under the objective of VOCAR to investigate the feasibility of using received signal levels either by themselves or in conjunction with other techniques for inferring refractivity conditions, Rogers et al. (1996) demonstrated a simple bias-correction method for fusing radio reception data with mesoscale models. In the refractivity sensing effort, a multi-wavelength Raman lidar produced excellent vertical humidity profiles (Philbrick and Blood, 1995) and satellite sensing techniques were developed for incorporation into automated knowledge-based predictive and assessment systems (Helvey et al., 1995).

The second measurement program specifically designed for coastal environments is called EO Propagation Assessment in Coastal Environments (EOPACE) (Littfin and Jensen, 1996; Zeisse et al., 1996). EOPACE started in 1996 and has three primary objectives. The first addresses measurement, modeling, and prediction of large, surf-generated aerosols that are important for sea skimmer missile detection; the second is to provide comprehensive data for the development of mesoscale models that are capable of predicting EO propagation conditions, and the third is to provide a testbed for infrared surveillance systems. Participants in EOPACE include the Naval Command, Control and Ocean Surveillance Center, the Naval Air Warfare Center, the Naval Research Laboratory, the Naval Postgraduate School, the Pennsylvania State University, and researchers from Australia, the Netherlands, and the United Kingdom. Initial results include dramatic visualizations of aerosol plume generation in the surf zone and important effects of both large aerosols and refraction on near-surface infrared propagation.

CONCLUSIONS

Atmospheric effects assessment for military operations is far too costly and too complex to be carried out in isolation. Within the U.S. military service branches, DDR&E has a long and successful record of facilitating such coordination. Various research organizations within NATO have provided superb opportunities for fruitful joint research and possess a proud record of significant accomplishments. In today's competitive environment, it is mandatory to produce quantifiable results in joint R&D efforts in short order. There are, however, also long-term pay-offs that may even be difficult to trace and important intangible benefits like getting to know different research facilities, approaches to solving problems, work environments, and cultures. These aspects should also be considered when planning cooperative arrangements rather than relying solely on *quid pro quo* arguments.

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